# Summary of the 3 May 2023, Videocon

Attendees were:

***Jørgen, Kiran, Rafa, Rachel, Roger, Sergei, Sushant, Sylvain K., Jesper, Tim, Sasha, Sylvain B., Savita***

**Rafa** mentioned some slight issue in the background fit with the Bayesian fitting code for stars because of the two humps in the GOLF data but this should not affect the frequencies and the splittings. He hopes to have more time to work on the project this summer during a visit to Boulder.

**Rachel** presented her helioseismic analysis of AIA data. She analyzed the NUV line at 170nm (believed to be formed in the upper photosphere) that shows a clear signature of the 5-min oscillations. This work is based on a poster presented in 2014. In the PSD, AIA does not seem to have too much granulation compared to HMI. The high-frequency noise is also higher than in the velocity measurements. She looked into the coherence and phase by computing the frequency dependent correlation between two datasets. Between the continuum and velocity of HMI, there is a high coherence for the main modes ($l = 0 - 3$). We can see low coherence in the region of $l = 4, 5$ (they are not seen not in intensity but in velocity). However, there is higher coherence AIA and HMI velocity in the modes and even in the background. It is not clear why. The phase is showing 2 regimes above the 5-min band and at lower frequency with the granulation. Rachel then recently downloaded time series with the DATAMEAN keyword and removed spikes. The yearly variation can be clearly seen. We can also see the ageing of the detector with a long-term downward trend. Around solar maximum, the rotation period can be detected. At minimum of activity we do not see that modulation. There is also a daily variation that increases with time. The question is to understand how to detrend the time series and subtract the rotation modulation. For now, she is just dividing by a 151-point running mean and subtract 1 to have a relative intensity variation. The 13-year spectrum obtained shows spikes but acoustic modes go down to 1330 $\mu$Hz. From fitting the modes, the asymmetry of the modes is rather positive than negative. Frequencies look reasonable and the linewidths also come out nicely. The violin plots for the splittings and the visibility functions were shown. At low frequency the splittings do not seem so good but they get better for high frequency. The normalization could be improved. Because of the long-term trends, the amplitudes are not so reliable but the linewidths might provide information that is useful. **Tim** mentioned that no fitting was done with AIA. Tim was concerned about the fact that AIA was not evenly spaced but Rachel found that they have tidied up the cadence recently. **Jesper** was interested in a quantitative estimate of the comparison of different instruments. **Rafa** was wondering why Rachel needed to remove the rotation signal to have clean signal for the modes, as for GOLF he does not need to do it and there is no leakage of the rotation into the modes. Rachel is taking out a quite short running mean because the background is going up and down with activity. Rafa also suggested to use a triangular filter instead of a moving mean to avoid the wiggles. Rafa will see if he can also run his calibrating pipeline for Kepler.

Rachel's slides on the AIA analysis are included with this summary.

**Sergei** asked a question to Rachel about the MDI/HMI fitting she showed at the previous meeting. He was asking what MDI/HMI meant exactly. These data were produced for the PHOEBUS project by Rafa and Thierry Appourchaux, with time series for $l = 0$ concatenating MDI and HMI and interpolation of HMI onto the 60min cadence of MDI. Sergei suggested to analyze them separately. Rachel tried that but the results were a bit different. In his comparison of MDI and HMI he found that the MDI noise is dominated by Shutter noise and it is seen almost as white noise. Jesper confirmed that MDI has some

shutter noise and it depends on the timing in the mission. However, there should not be any noise at p-mode frequency due to the stability of any element in HMI or MDI. Sergei concluded that in his opinion HMI is superior to MDI for low degree modes.

**Jørgen** reported on his work to study the statistics of the tachocline fits, including Sylvain K.'s results, doing an MCMC analysis based on the inversion results and the reported standard deviation. He was then running the fit to look at the distribution. He showed the results for the Model 2 and the $a$ coefficients from Jesper for different latitudes. The location of the tachocline, $r_c$, and the width, $w$, central rotation rate $\Omega_c$ and rotation at the edges of the CZ (tachocline and surface). Some results go quite far from the input value. We get an idea on the errors with the widths but he needs to get into the regularization parameters. The corner plots show that there is little correlation between parameters except between the rotation at the tachocline and the one at the surface. For a latitude of 75deg, the correlation becomes even stronger. The machinery is there and can be run for other results. Looking at the inversion parameters, as expected the standard deviation in the width decreases with increased regularization both in radius and latitude. It is similar for the other parameters but for the FWHM in a more complex way. Rachel has results for other inversion cases, which will be similarly analysed. He then showed the results from Sylvain K.'s RLS-OMD results for error-free data. These results seem to be heavily regularized. The errors are larger than the previous case. Sylvain K. will look back at his results and discuss with Jørgen.

Notes on this analysis are provided with this summary.

The next meeting, we will go through the list of tasks to see what has been done and what is left to be done.

Next meeting will be held on 12th June 2023.

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## Open Action Items

A.6: Find optimal inversion parameters and produce results on standard form (all inverters)

A.7: Include measures of inversion resolution in radius and latitude in numerical output (all inverters)

A.25: Investigate the effects of the differences between two leakage matrices for low-degree ($\ell$=1) modes (JS, SGK, TL)

A.33a: Create a short document on the results of A.33 (RKU)

A.38: Inversions for non-optimal parameters to be sent to JCD (SB/HMA/PD)

A.50: Comparison between different RLS results (JCD)

A.51: Mode set for core inversion below 0.2 $R_{Sun}$ (RAG)

A.53: Some details of the Antonio's code for the paper (SGK)

A.55: Averaging kernels and the solutions to be sent to JCD for comparison (SGK)

A.64: Jørgen to communicate directly with Antia/Sarbani/Prithwitosh for their results to complete A.38.

A.68: Check input for differences in Table 3 and Fig. 14 in Paper I draft version. (RH and JCD)

A.72: Compare errors obtained from Monte Carlo and modified AB codes (HMA, SB, PD)

A.76: Jesper would look into the files to recall where GONG data were processed through the MDI global pipeline

## Full list of Action Items

Since we have started identifying various tasks by the item numbers, it is decided to keep the same numbering as we move forward. Now onwards, the action item list will have all old and new tasks.

Note: Actions have already been taken on the highlighted items. No further work is required.

**Carryover action item list**

~~A.1: Use fixed and reasonable plot limits in plots of inversion result differences (JC-D)~~
~~A.2: Investigate causes of excessive error estimates in inversions of individual splittings (SGK, AE-D)~~
~~A.3: Inversion results for artificial data on standard form (RH)~~
~~A.4: More extensive results on standard form (SV)~~
~~A.5: Consider determination of~~ statistical errors ~~and centres of gravity of averaging kernels (SB, HMA)~~
**A.6: Find optimal inversion parameters and produce results on standard form (all inverters)**
**A.7: Include measures of inversion resolution in radius and latitude in numerical output (all inverters)**

***February 13, 2020***

A.8: ~~Consider ways of displaying resolution results (JC-D)~~
~~A.9: Analysis of averaging kernels, determination of radial and angular extent (JCD, RH)~~
A.10: [Duplicate of A.7]
~~A.11: Understand differences found by Sarbani and Antia in a coefficients, relative to Sasha's (SB, HMA, AK)~~

***March 17, 2020***

~~A.12: Input for the paper based on the work discussed at the meeting (SB, HMA) (included in meeting summary)~~
~~A.13: Format for averaging kernels in (x, y) grid (JCD)~~
~~A.14: Notes on today's (March 17, 2020) discussion (SVV) (included in meeting summary)~~

***April 22, 2020***

~~A.15: Compare and consolidate treatment of background in analyses of GOLF and BiSON data (RH, RAG)~~
~~A.16: Analyze SOLA inversion results with different trade-off parameters, attempting higher resolution at the expense of higher errors (RH, JCD)~~
~~A.17: Surface rotation results to be provided in numerical form (RKU)~~

~~Of course A.2 still needs action from Antonio, and for A.9 I hope to get a representative selection of averaging kernels for the SOLA inversions from Rachel~~.

***May 27, 2020***

~~A.18: Compare different determinations of degree 1 - 3 splittings, including spatially resolved data (RG, RH, SK, JS, TL)~~
~~A.19: Compare torsional oscillations in Mt Wilson surface rotation observations with helioseismic results (RU, RH)~~
~~A.20: Test analyses of averaging kernels with well-behaved (e.g., double-Gaussian) artificial kernels (JC-D)~~
~~A.21: Provide averaging kernels from SK - AE-D inversions (SGK)~~ This is added to Task A.55.

~~A.22: Results from SK- AE-D inversions to be uploaded before next meeting (SGK)~~
~~A.23: Upload the updated summary file on calculating the properties of averaging kernels (SB)~~

***July 1, 2020***

~~A.24: Re-compute splittings for Sun-as-a-star observations using background similar to RG/AMB (RH)~~
**A.25: Investigate the effects of the differences between two leakage matrices for low-degree ($\ell$=1) modes (JS, SGK, TL)**

~~A.26: Investigate the differences between the zonal flows from Roger's data and the helioseismic method (RH)~~
~~A.27: Validate averaging kernels near or at the equator (JCD)~~
~~A.28: Averaging kernels to be sent to JCD for the action item A.27 (SB and RH).~~

***August 3, 2020***

~~A.29: Analysis of resolution in averaging kernels as a function of trade-off parameters (RH, JCD)~~
~~A.30: Fits from Sun-as-a-star observations to be uploaded to Dropbox (RAG)~~
~~A.31: Low-degree mode fits using Rafa's frequencies as initial guesses (JS)~~
~~A.32: Notes on the analysis of averaging kernels to be uploaded to Dropbox (JCD).~~

***September 9, 2020***

~~A.33: Analyze rotation rate from observations using different spectral lines (RKU)~~
**A.33a: Create a short document on the results of A.33 (RKU)**
~~A.34: Obtain insight on the HMI observables and their data quality (RH to discuss with JS)~~
~~A.35: Combined with A.30.~~
~~A.36: How the smoothing parameter is used in the inversion code? (RH)~~
~~A.37: Another set of averaging kernels to be sent to JCD (RH)~~
**A.38: Inversions for non-optimal parameters to be sent to JCD (SB/HMA/PD)**
~~A.39: Notes of the averaging kernels analysis discussed at the meeting to be uploaded to Dropbox (JCD).~~

***October 14, 2020***

~~A.40: Hare and hound results with normal smoothing (SB, HMA).~~
~~A.41: Upload all low-frequency tables to the Dropbox (KJ).~~
~~A.42: plots of the cuts of averaging kernels for $\mu$ =1 to be included in the document (JCD).~~
~~A.43: Averaging Kernels for Model 2 to be sent to JCD (RH).~~

***November 25, 2020***

~~A.44: Draft of Paper II by next meeting (RAG).~~
~~A.45: Introduction: a few lines on surface differential rotation and why it is important (RKU).~~
~~A.46: Introduction: reference(s) for the first evidence of sub-surface zonal flows and their time-dependence (JS).~~
~~A.47: Introduction: a short paragraph on core and the radiative zone (RAG).~~
~~A.48: Results on the RLS inversion using his code (JS)~~
~~A.49: Convert JS results to a standard format for comparison (RH)~~
**A.50: Comparison between different RLS results (JCD)**
**A.51: Mode set for core inversion below 0.2 $R_{Sun}$ (RAG)**
~~A.52: Incorporate suggestions in Paper I (JCD)~~
**A.53: Some details of the Antonio's code for the paper (SGK)**

***January 12, 2021***

~~A.54: Upload plots from modified SGK/AED code (SGK/KJ): Link is included in the meeting summary.~~

**A.55: Averaging kernels and the solutions to be sent to JCD for comparison (SGK)**
~~A.56: Details of the two RLS methods (SB/HMA, JS/RH)~~
~~A.57: Discussion on low-degree modes (RAG, RH, AMB, JS, SM, SGK)~~

***February 17, 2021***
~~A.58: Coordinate with concerned persons for various data sets to be included in Paper II (RAG)~~
~~A.59: Discussion with Antia on AB formalism (Sarbani)~~
~~A.60: Upload results on the comparison of AB and SH averaging kernels (JCD)~~

***March 17, 2021***
~~A:61: Jørgen and Rachel to discuss off-line the issues with Model 2 solution.~~

***April 17, 2021***
~~A:62: Send the link of frequency tables from Jesper's fitting (KJ)~~
~~A.63: Eigenfunctions to be sent to Jørgen for comparison (AGK)~~
**A.64: Jørgen to communicate directly with Antia/Sarbani/Prithwitosh for their results to complete A.38.**
~~A.65: Share draft/outline of Paper II on overleaf (RAG).~~
~~A.66: Share latest version of Paper I (JCD)~~

***May 25, 2021***
~~A.67: Share latest results (JCD~~)

**July 7, 2021**
**A.68: Check input for differences in Table 3 and Fig. 14 in Paper I draft version. (RH and JCD)**

***August 30, 2021***
~~A.69: Review previous results on the SOLA inversion (RH and JCD~~).
~~A.70: Significance of the iterative method in AB inversions (HMA and PD)~~

***September 30, 2021***
~~A.71: Contact Sylvain K for the update on SGK/AE-D inversion results. (JCD)~~

***November 3, 2021***
No new action item was added.

***December 9, 2021***
No new action item was added.

***January 17, 2022***
**A.72: Compare errors obtained from Monte Carlo and modified AB codes (HMA, SB, PD)**
~~A.73: Sasha to send the link of Google Drive to JCD again for kernels and eigenfunctions in forward modeling.~~

***February 14, 2022***
~~A.74: Finalize the start and end dates of data sets for Paper II (RAG)~~
~~A.75: Carry out comparison of eigenfunctions (JCD, AGK)~~

***March 14, 2022***
No new action item was added.

***April 20, 2022***
A.76: Jesper would look into the old files to recall the procedure and parameters he had used for processing GONG data through the MDI global pipeline.

***May 25, 2022***

No new action item was added.

***July 06, 2022***
No new action item was added.

# Appendix A: Fitting low-degree splittings

In the meeting of the 29 March 2023, Rachel showed results of her analysis of the L=0 GONG and the combined MDI/HMI data for the low-degree modes.

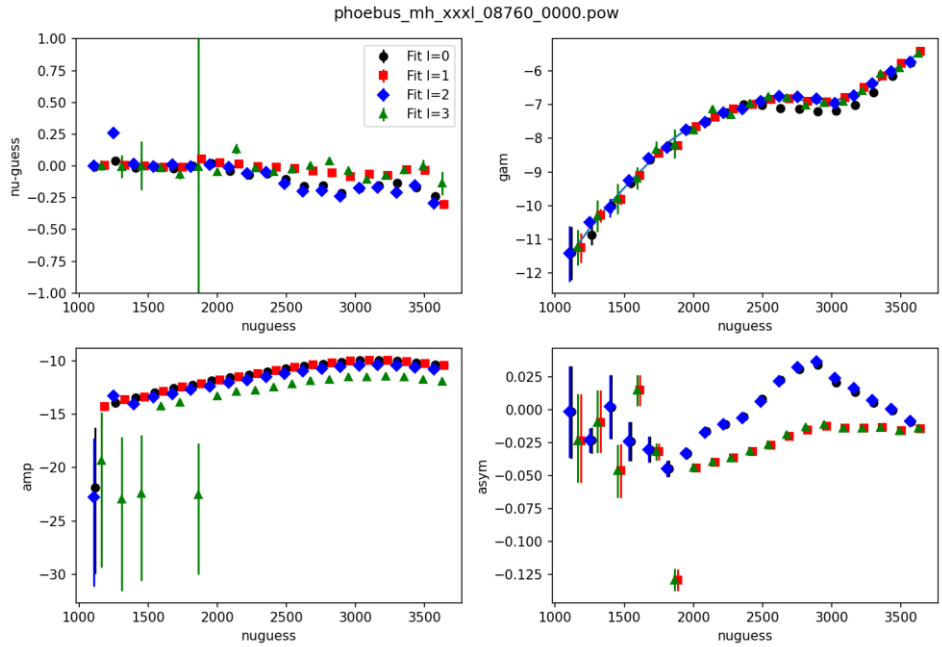


*Figure 1: MDI/HMI fitting results with a 44 μHz window. Top left panel: difference between the fitted frequency and the guess. Top right panel: fitted widths of the modes. Bottom left panel: fitted amplitude of the modes. Bottom right panel: fitted asymmetry of the modes.*

Various low-degree frequency fittings were performed, described in the document **`lO spectrum fits.pdf`**, which is provided with the summary.

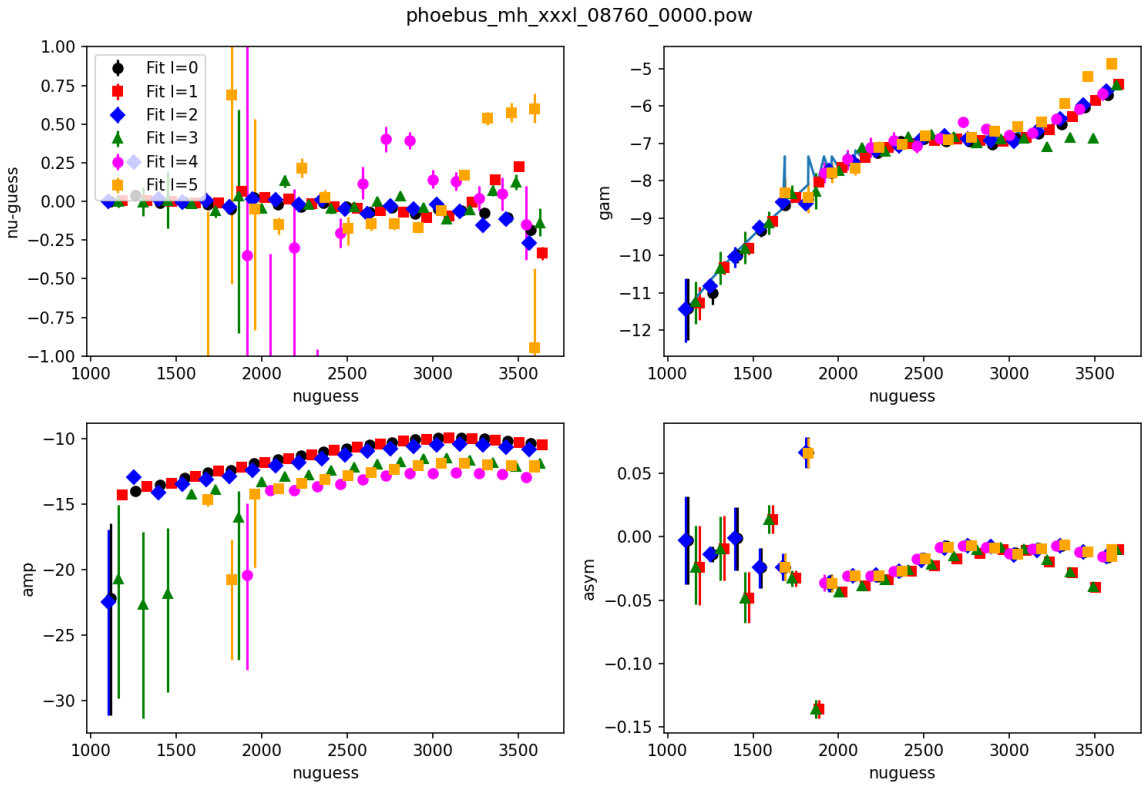


*Figure 2: MDI/HMI fitting results with a 74 μHz window.*

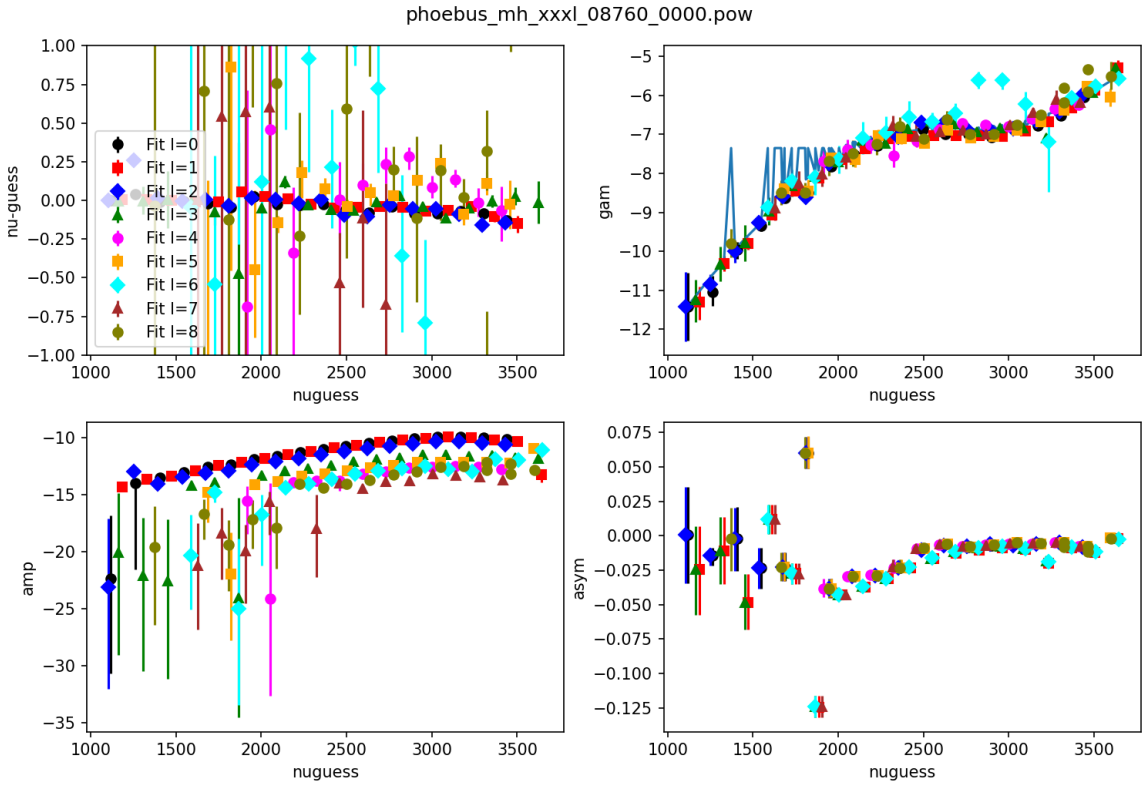


*Figure 3: MDI/HMI fitting results with a 74 μHz window.*

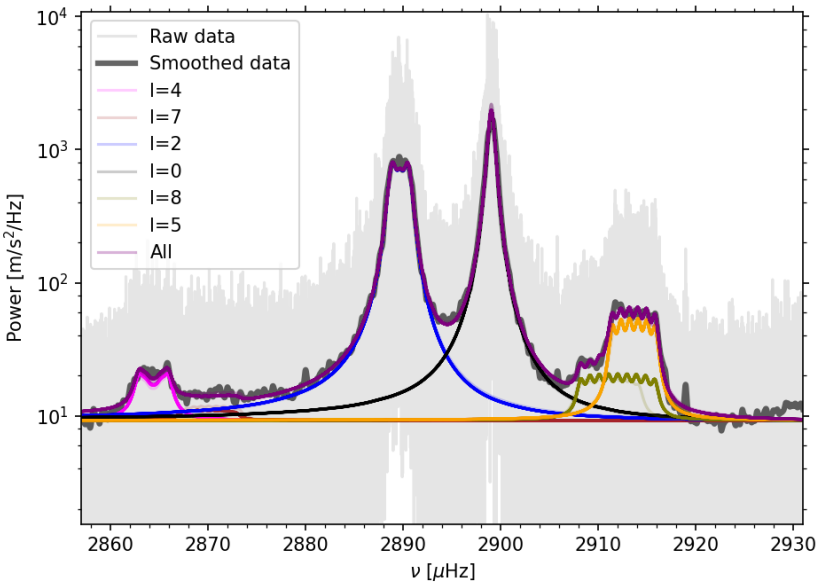


*Figure 4: Fitting of the modes up to l=8 with MDI/HMI data using a 74 $\mu$Hz window. We can see the l=8 mode.*